equipment list in Appendix (iii)). The test signal was again set so as to produce a 12dB SINAD ratio at the receiver output. This level corresponded to the reference sensitivity i.e −117dBm. The frequency of the test signal carrier was measured as 165.888259 MHz. The level of the interfering signal (a single carrier) was then increased so as to produce a degradation in the SINAD ratio and the frequency of the interfering signal was adjusted within the limits of the two adjacent channels so as to maximise this degradation of the SINAD ratio.

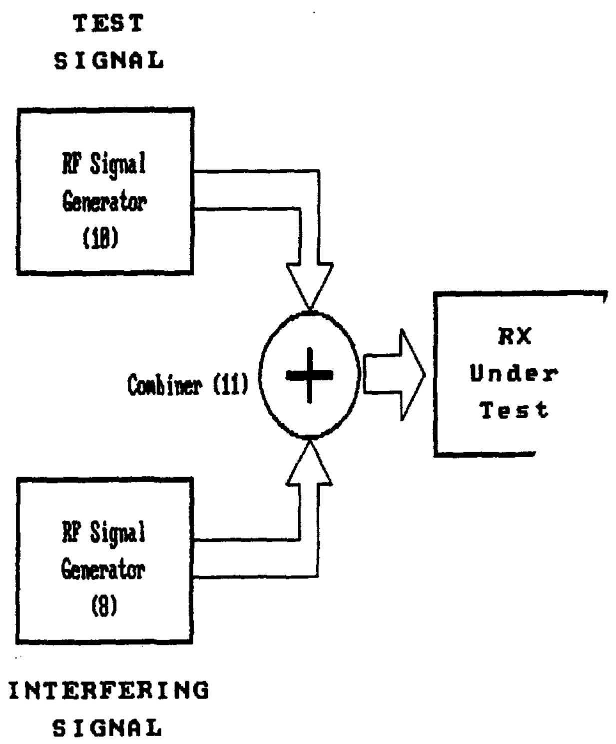


Fig 2.24 Adjacent Channel Test Configuration.

Measurements of interfering signal power level that degrade the SINAD reading to 6dB were then taken. As well as adjacent channels, measurements at two channel spacings above and two channel spacings below were also taken (second upper and second lower channels) and the results summarised in table 2.2 below. The adjacent channel selectivity is the ratio between the reference sensitivity (−117dBm) and the interfering signal power level.

Channel	Frequency (MHz)	Power Level (dBm)	Selectivity (dB)
Upper adjacent	165.892740	−36.4	80.6
Lower Adjacent	165.883000	−29.3	87.7
Second Upper	165.898250	−30.3	86.7
Second Lower	165.878000	−24.8	92.2

Table 2.2 : Adjacent Channel Selectivity

The draft DTI specification gives a minimum adjacent channel selectivity of 50dB, which gives the equipment a 30dB margin over the specification.

2.2.3 Spurious Response Rejection

The test was carried out as section 5.3.2 of the revised DTI spec. Two signals were applied to the input of the receiver; a test signal and an interfering single carrier. The test signal level was set so as to produce a 12dB SINAD ratio at the output of the receiver, corresponding to the reference sensitivity of −117dBm. The interfering signal level was then set at +86dBμV (emf) or −27dBm.

The interfering signal was swept across the specified frequency range (100kHz to 2GHz) and the effect on the SINAD ratio observed. It was found that, in the specified frequency range, no degradation of the SINAD ratio occurred when a −27dBm signal was applied in such a way. This implied that the spurious response rejection was better than 90dB. This is because the result is calculated as the difference between the test signal level (−117dBm) and the level of interfering signal that causes a reduction of the SINAD ratio to 6dB. Hence, as no response was observed, the spurious response rejection must be greater than 117 − 27 = 90dB. The level required in the DTI specification is 70dB.

2.2.4 Intermodulation Response Rejection.

The test was carried out using the test configuration shown in figure 2.25 below. The input test signal level was set to produce a 12dB SINAD ratio at the output of the receiver (−117dBm) and then the power level was increased by 3dB to −114dBm. The two interfering signals were then applied, one (f_n) at 10 channel spacings plus 1kHz, the other (f_r) at 20 channel spacings plus 1kHz. The levels of the interfering signals were then kept equal but adjusted so as to reduce the SINAD ratio back to 12dB. The levels were then measured at the input to the receiver.

The intermodulation response rejection is the ratio of the unwanted signals to the reference sensitivity (the 12dB SINAD ratio). The results are given below.

Reference Sensitivity = −117dBm

Interfering Signal

f_n = 165.93900MHz

f_r = 165.98900MHz

power level = −38.2dBm

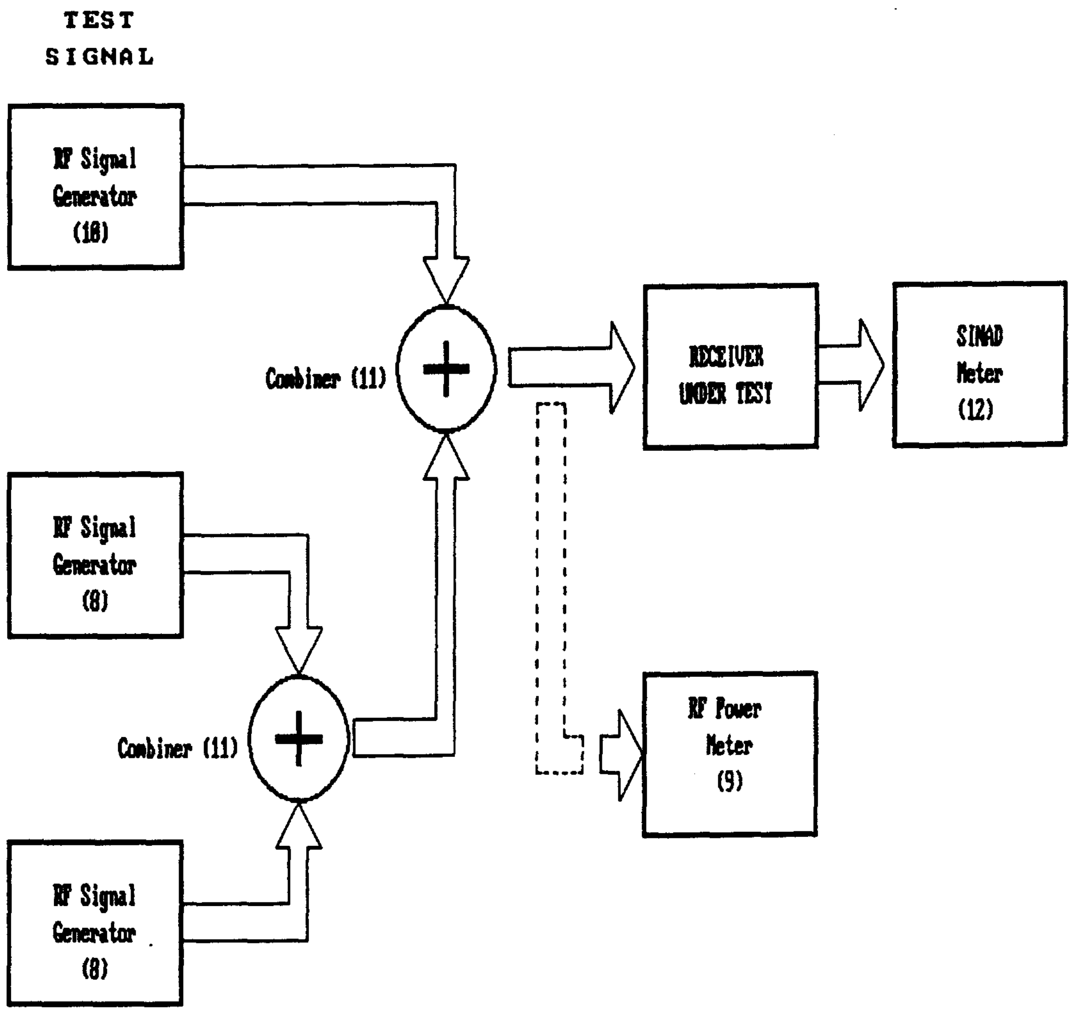


Fig 2.25 Intermodulation Test Configuration.

Hence the intermodulation response rejection can be calculated at 78.8dB, which is 1.2dB below that required in the specification. Note that the test procedure used is as BS6160:Part 5:Section 14.5.2. and that the calculation is carried out relative to the reference sensitivity. In the draft DTI specification the intermodulation rejection is calculated relative to 1mV. However, the standard method outlined in BS6160 was adopted as it seemed more appropriate.

2.2.5 Blocking.

The test was carried out as per the revised DTI spec, section 5.5.2. Two signals were again applied to the input of the receiver, with the wanted input signal being adjusted to +6dB relative to an emf of 1μV (which corresponds to 1μV pd). The interfering (single carrier) signal was then adjusted in the frequency range 2 to 10MHz either side of the receiver frequency. The resulting power levels for the unwanted signal that produced a 6dB degradation in the SINAD ratio are given below. The conversion from watts to volts was made using a figure of 50Ω (as measured) for the input resistance of the receiver.

	Frequency (MHz)	Blocking Level: dBm	dBμV emf
Above Band	168.18830	−13	100
Below Band	163.88826	−1.8	111

The draft DTI specification permits a minimum level of 90dB relative to an emf of 1μV. Hence the equipment can be seen to be within the specified limits.

2.2.6 Spurious Emissions.

The receiver was connected directly to the input of a spectrum analyser (see Appendix (iii) item 6) and the spectrum over the range 100kHz to 2GHz observed. There were found to be several emissions in the 0 to 200kHz range and another single emission at 1.7GHz. These are shown in figure 2.26 and figure 2.27. The levels of the emissions can be seen to be less than −70dBm. The draft DTI spec permits a level of 2nW, which corresponds to −57dBm, hence showing the equipment to be within the specification by a margin of 13dB.

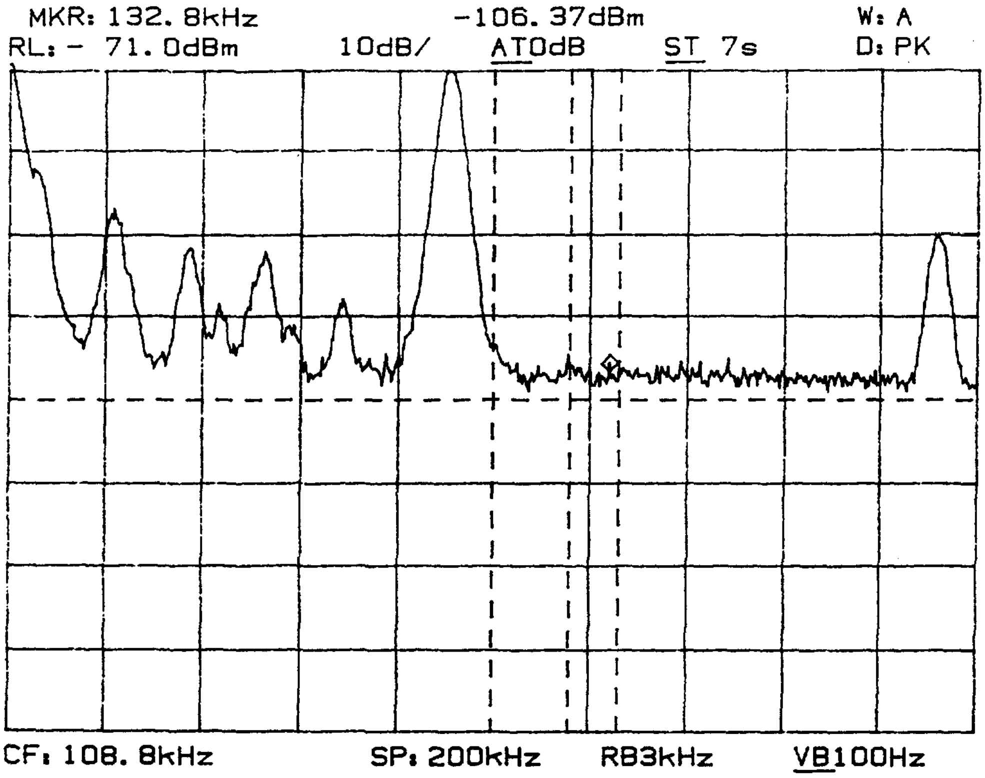


Fig 2.26 Receiver Spurious Emissions.

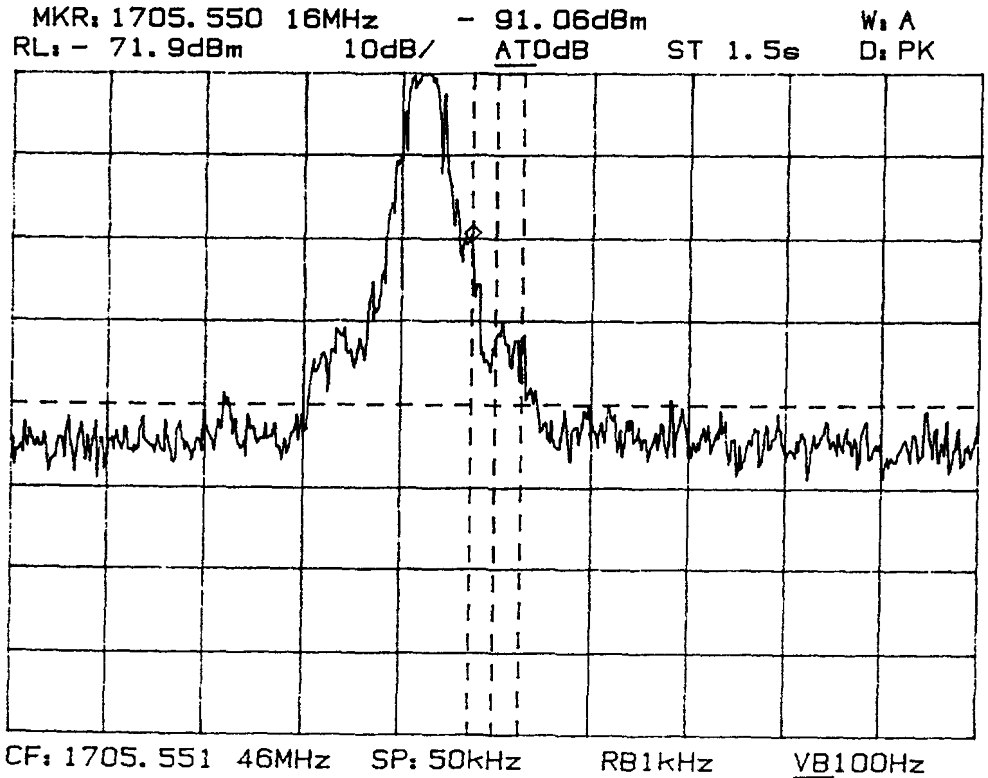


Fig 2.27 Spurious Emission At 1.7GHz.

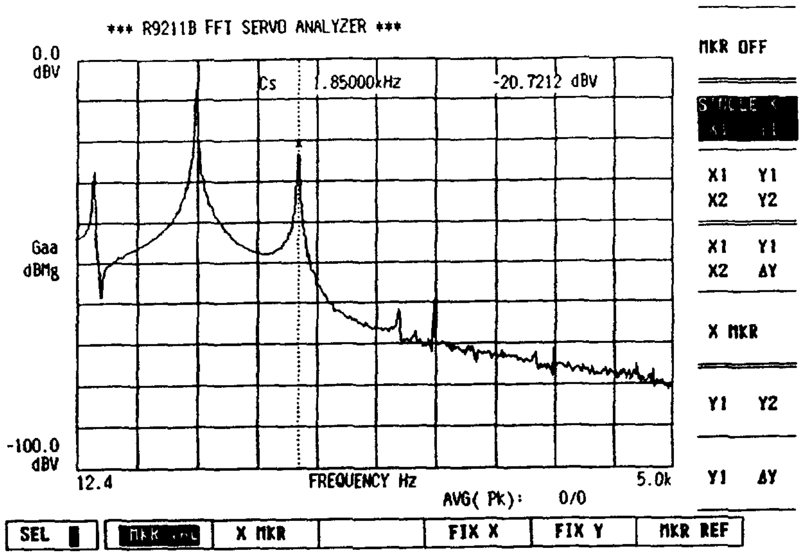


Fig 2.28 (a) Output Of Product Detector.

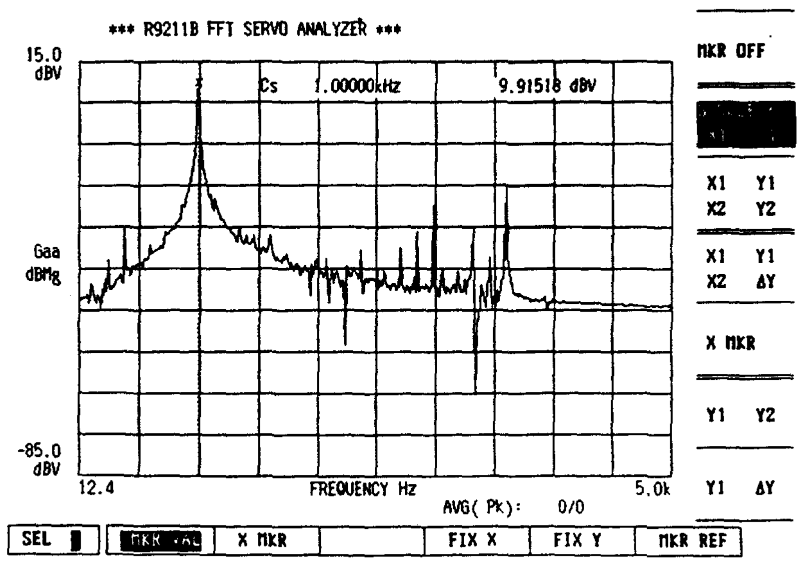


Fig 2.28 (b) Output Of Audio Stages.

2.2.8 Co-Channel TTIB-Tone Test

The test was done in a qualitative style in order to investigate the effects of another carrier being present at a similar frequency (within a few Hz) as the in-band pilot tone. The test signal can be seen in figure 2.29, showing the 1kHz audio tone 850Hz below the pilot.

An interfering tone was then brought up and the effects observed. When the tone was of a similar order of magnitude to the pilot tone and offset by a few Hertz then the receiver was found to switch lock between the two signals in an oscillatory manner. This resulted in a rapid change in frequency of the 1kHz test tone.

A measurement of the level of interfering signal, relative to the pilot, that produced a noticable degradation in the 1kHz tone was then taken. A plot of the interfering signal is shown in figure 2.30 and the effect it had on the test signal in figure 2.31. As can be seen, a level of 30dB down on pilot appeared to be the point at which the interfering tone becomes noticable. Figure 2.32 shows the effects the interfering signal has on the audio output.

An audio test was performed on the equipment as it was found that taking a SINAD measurement was unreliable. This was as a result of the way in which the 1kHz tone tended to jump up and down in frequency by an amount determined by the separation of the pilot and interfering signal.

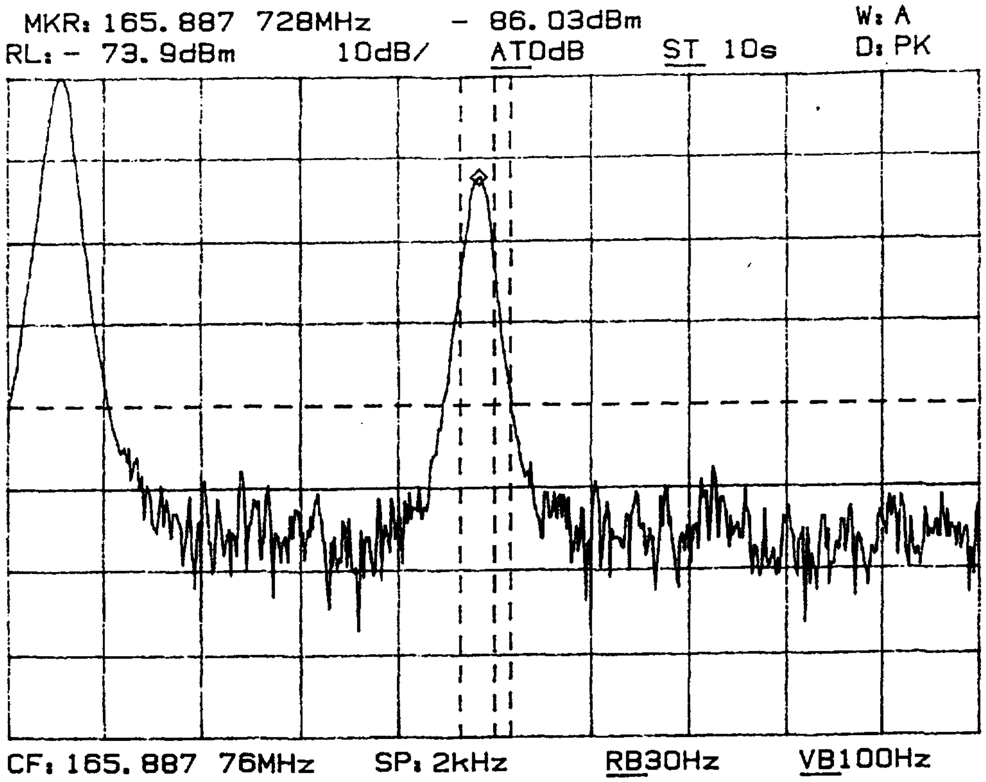


Fig 2.29 Co-Channel TTIB Tone Test Signal.

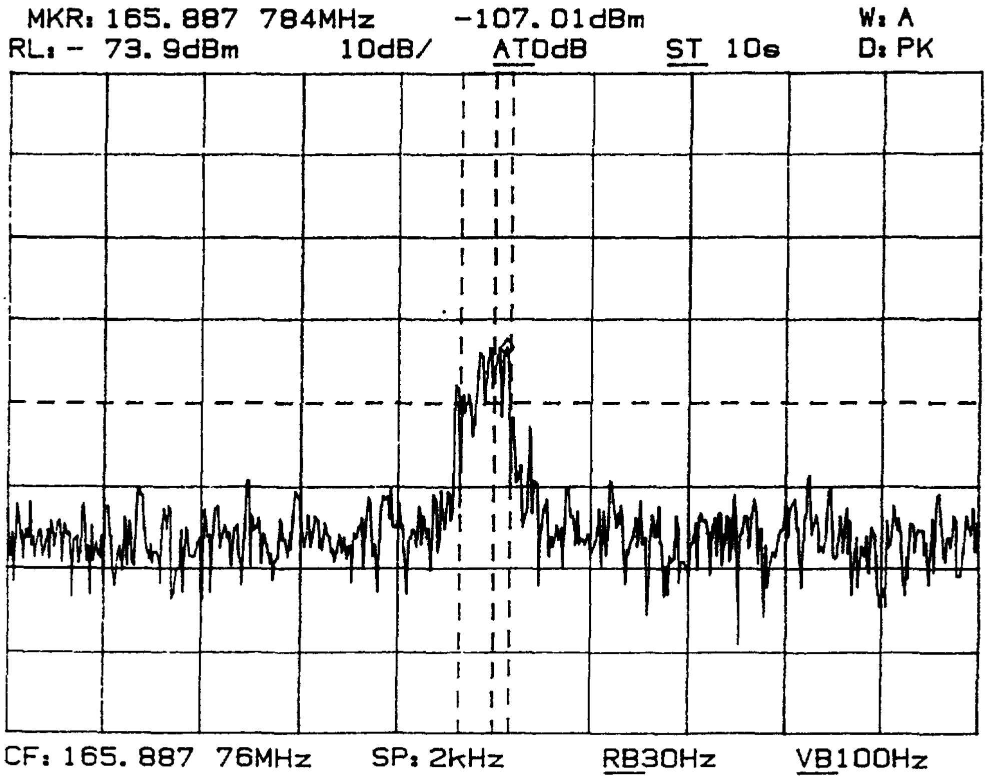


Fig 2.30 Interfering Tone

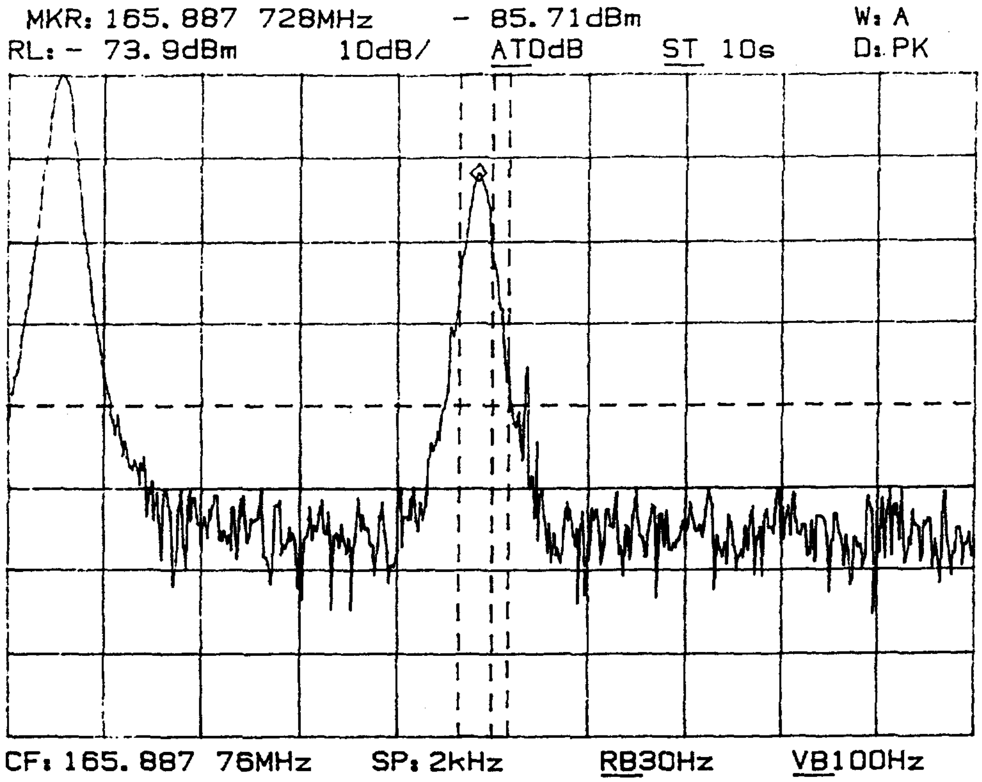


Fig 2.31 Effect Of Interfering Tone On Test Signal.

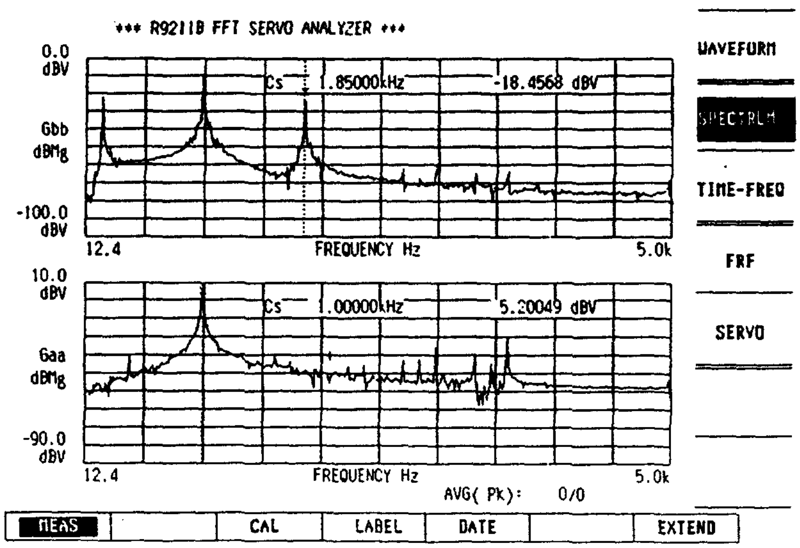


Fig 2.32 Audio Output.

Upper: Output of Product Detector
Lower: Output of Audio Stages

2.3 Summary.

The following is a summary of the performance of the SSB equipment under test. It also shows the performance relative to the first draft of the DTI specification.

Transmitter Tests.	Results	Pass/Fail	Margin
2.1.1 Frequency Error.	a) 95Hz	pass	205Hz
	b) 3Hz	pass	295Hz
2.1.2 Peak Envelope Power.	25W		
2.1.3 Audio Frequency Response	N/A		
2.1.4 Adjacent Channel Power.	74dB	pass	19dB
2.1.5 Spurious Emissions.	-81dBm	pass	45dB
2.1.6 Intermodulation Attenuation.	48dB	pass	33dB
2.1.7 In-Band Intermodulation.	30dB		

Receiver Tests.			
2.2.1 Sensitivity	0.3μV	pass	0.7μV
2.2.2 Adjacent Channel Selectivity	80dB	pass	30dB
2.2.3 Spurious Response Rejection.	>90dB	pass	>20dB
2.2.4 Intermodulation Response.	78.8dB	fail	-1.2dB
2.2.5 Blocking.	100dBμV	pass	10dB
2.2.6 Spurious Emissions.	-70dBm	pass	13dB

As can be seen, the equipment passes all the tests with the exception of the receiver intermodulation response. It should be noted that with the ALC and VOGAD disabled there exists a possibility of Power Amplifier (PA) overdrive which may have degraded the unit's performance. Thus, the system may perform better than indicated by these results if tested with the ALC and VOGAD operative.

With reference to the receiver intermodulation response, the test method used was as specified in BS6160, which is different to that outlined in the DTI specification. In the method adopted in these tests, the test signal was set at 3dB above the reference sensitivity (corresponding to −114dBm) and in the DTI procedure the test signal level is set at 1mV. Hence the limit given in the DTI specification may not be applicable to the test procedure in BS6160.

2.4 Comments on Second Draft of DTI Specification

It is noted that the second draft of the DTI testing specification is now available. The testing methods are somewhat different in places to the first draft. For receiver tests, instead of the standard 12dB SINAD ratio being used, a psophometricaly weighted SND/ND ratio of 20dB is used.

Also, a capacitive line coupler and precision attenuators are used for transmitter intermodulation attenuation measurements instead of circulator or resistive/isolator configurations. It is considered that the lack of isolation introduced by this change may lead to problems in ensuring that the intermodulation products are produced at the transmitter output and not at other interfaces in the test circuit.

In addition, for the transmitter adjacent channel power test, a single tone has replaced white noise as the modulating signal. It is felt that using a single tone may not represent as realistic a situation or as stringent a test as the original white noise modulation.

3. Field Trial Implementation.

To assess the relative performance of the three modulation schemes under test (AM, FM and SSB) two basic types of test were used. These were the Diagnostic Rhyme Test (DRT) and a Bit Error Rate (BER) measurement.

3.1 Voice Measurements.

The voice quality of the systems under test were investigated using the DRT[19,20]. The test is constructed from a list of pairs of words. Each pair rhymes and is taken from the Harvard PB word lists, such that the list is phoneticaly balanced. Test tapes were then made by taking one word from each pair and recording these words in various orders. The words were spoken regularly at a word spacing of about 1.5s. Three tapes were available (two female voices and one male) and each had two associated word lists: one list of pairs of rhyming words and one list of single words that corresponded to the words actually spoken on the tapes.

These test tapes were then transmitted over the radio link and the results recorded. These end recordings were then analysed by playing them back to a panel of listeners who were asked to identify which word they thought they heard from the list of pairs of words. The resulting scripts are then scored for response accuracy and the results averaged.

The DRT method for assessing speech quality removes some of the problems normally associated with speech interpretation. One of these is the test message itself. Using DRT the speech is free from any contextual information which is normally a very random and unquantifiable effect. Also, the absence of this contextual information makes the test more repeatable and the use of untrained listeners is possible.

3.2 Data Measurements.

The Bit Error Rate (BER)[21,22] is a measurement of a systems ability to transmit data. The test is implemented as shown in Fig 3.1 below.

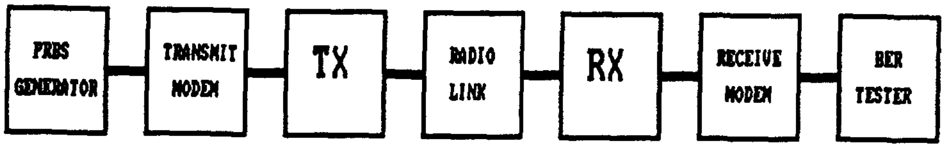


Fig 3.1 Measurement of Bit Error Rate.

The pseudo random bit sequence (PRBS) generator produces a sequence of a fixed length. Within this length the bit stream appears random. The PRBS used was $2^{15}-1$

The three main factors that affect the characteristics of a received signal are:

a) signal strength

b) fading depth

c) fading rate

The first two are functions of route and the last a function of vehicle speed (since other contributing factors, such as frequency, were constant). Hence routes were required that would provide a range of signal strengths in three bands as indicated below.

$$A > 36\mathrm{dB}\mu\mathrm{V/m}$$

$$36\mathrm{dB}\mu\mathrm{V/m} > B > 10\mathrm{dB}\mu\mathrm{V/m}$$

$$10\mathrm{dB}\mu\mathrm{V/m} > C$$

Stationary measurements were initialy carried out using a field strength meter and calibrated dipole antenna. This gave measurements of field strength in dBμV/m when used with a scaling factor. For field strength plots, a 5/8 170MHz whip antenna was used. It was found that the nominal 8dB gain of a 5/8 whip corresponded to the scaling factor used with the calibrated dipole at 170 MHz to convert from dBμV (emf) to dBμV/m. Hence, the field strength plots can be read directly in terms of dBμV/m. The bands were subdivided again into two fading types: shallow and deep fades. This then gave six possible types of route. Where possible, each of the routes was to be run at three speeds;

a) dead slow

b) 30 mph

c) 50 mph

After an initial survey of the area targeted for the trials, it was found that only one route could be run safely at 50 mph. A total of five routes in all were selected as being suitable for conducting constant speed runs safely and without causing excessive disruption to normal traffic. The routes are listed below:

ROUTE	FIELD STRENGTH	FADING DEPTH	SPEED
1) A217 (pre-roundabout) :	A :	shallow :	(a) and (b) :
2) A217 (post-roundabout):	A :	deep :	(a) and (b) :
3) A2022 :	B :	deep :	(a) and (b) :
4) A3 :	B :	shallow :	(a), (b), (c):
5) B2032 :	C :	shallow :	(a) and (b) :

A map showing the routes is given in Fig 3.2 and the associated field strength plots in Fig 3.3 (a) to (e).

All field strength plots were made at 30 mph using FM control channel transmissions (see Appendix (iii) items 2/4 and 2/5). During live runs, each route was run for approximately four minutes. This allows an accuracy of 3 in 10^6 for BER measurements (at 1.2k bps) and a DRT accuracy of better than 1%.


KINGSTON
21
22
Coombe

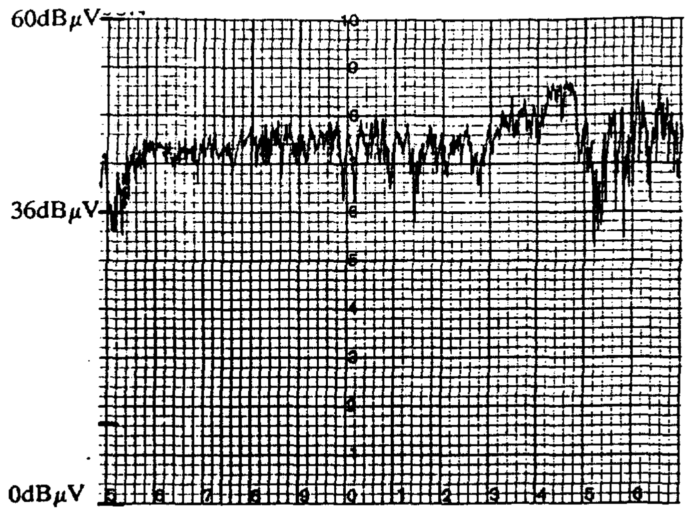
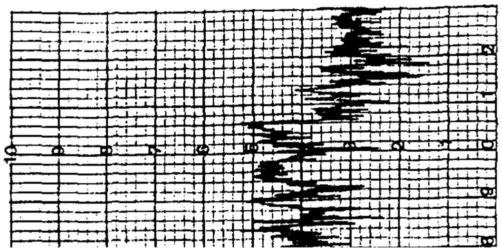
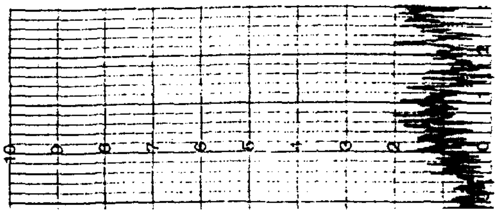


Fig 3.3(a) Route (1).





3.3.2 Baseline Experiments.

To obtain the desired baseline characteristics, the following combinations of modulation scheme and testing criteria were required on all five routes.

SSB with voice

SSB with data

FM with voice

FM with data

AM with voice

AM with data

This resulted in a total of 66 test runs. It must be noted that additional baseline measurements were also taken for the higher data rate experiments and are outlined in section 4.1.4 High Speed Data Rates.

3.3.3 Adjacent Channel Experiments.

These experiments were designed to quantify the effects of introducing a 5kHz SSB channel adjacent to a 12.5kHz AM or FM channel. In addition, the effect that two adjacent SSB channels would have on each other was also investigated.

Since the number of possible tests is greatly increased by introducing a second channel, a restriction was placed on the number of runs made. Hence the experiments were limited to three paths; routes (2), (3) and (4) and to 30 mph.

Continuous speech was chosen as the interfering signal and an appropriate tape prepared. The following is a list of the experiments undertaken.

SSB data	with	interfering	FM	speech
SSB voice	"	"	FM	"
SSB data	"	"	AM	"
SSB voice	"	"	AM	"
SSB data	"	"	SSB	"
SSB voice	"	"	SSB	"

FM data	with	interfering	SSB	speech
FM voice	"	"	SSB	"
AM data	"	"	SSB	"
AM voice	"	"	SSB	"

3.3.4 Co-Channel Experiments.

Also required were measurements of the effect of co-channel interference. Since these experiments would require an interfering signal at another location, the concept of a 'mobile site' was adopted. This idea is explained and illustrated in more detail in section 3.4 Equipment Configurations.

Due to the complex setting up of a mobile site, it was decided to restrict the number of experiments to only one route; route (3). This also reduced the number of required mobile site locations to a single site. A result of this was to greatly reduced the time required for pre-experiment work, since surveying mobile site locations reqiured a time consuming series of events.

i) Selection of possible site by map inspection.

ii) Drive both vehicles to possible site.

iii) Visual inspection of site for accessability and isolation.

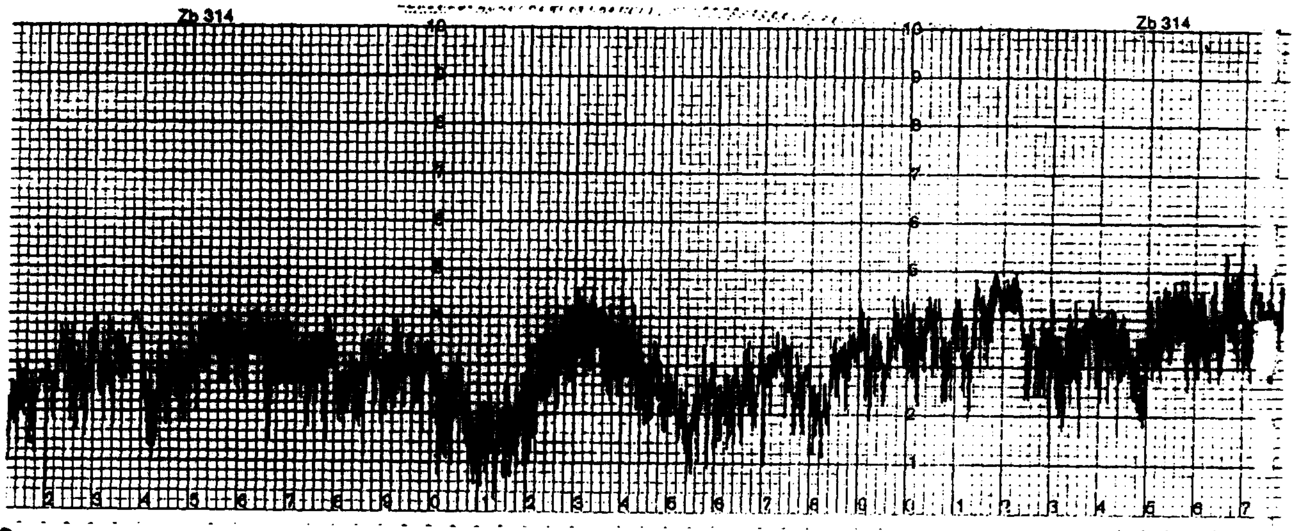
iv) Set up transmitter equipment.

v) Drive second vehicle to route (3) and take field strength plot

vi) Dismantle site and move onto next target location.

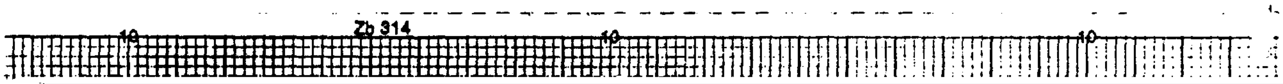
Once a suitable location for the mobile site had been selected (see Fig 3.2 Map indicating mobile site location), field strength plots were taken. Two different wanted to unwanted signal ratios could then be implemented using a 6dB power attenuator. Fig 3.5 and Fig 3.6 give the field strength plots of the mobile site transmitter, without and with attenuation respectively. The average protection ratios are 2dB and 8dB.

The same ten combinations of interfering conditions as stipulated in section 3.3.3 were again required. The combination of these and the two ratios of wanted and unwanted signal strengths gave a total of 20 runs for the co-channel experiments.



Start

Fig 3.5 Interfering Co-Channel Signal on Route 3: no attenuation



3.4 Equipment Configurations.

Two of the three systems under test utilised some form of trunking. The SSB and FM systems complied with the MPT1327 [24] trunking standard and the AM equipment used open squelch re-transmission (used for these trials with the consent of the DTI). Details of the mobiles and base stations used can be found in Appendix (iii), items 2/8, 2/9 and 2/10.

A schematic diagram showing the basic system components is given in Fig 3.7 below.

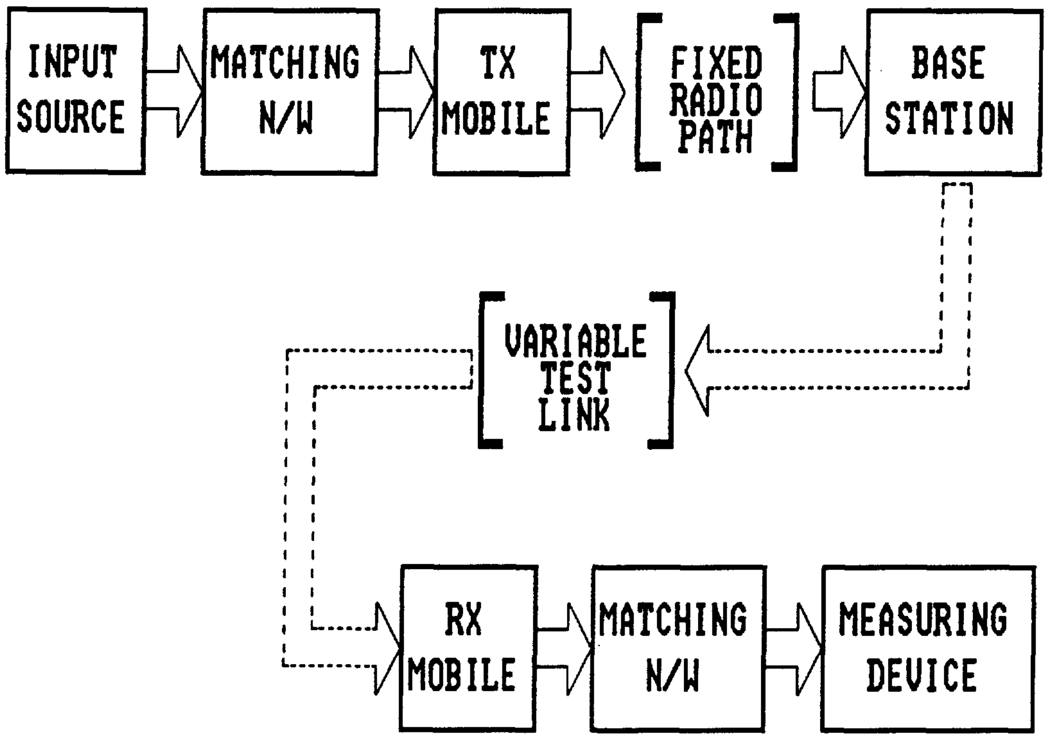


Fig 3.7 System Configuration.

3.4.1 Base Station and Adjacent Channel Configurations.

The main site base station configuration is shown in Fig 3.8 and was kept the same for all three modulation schemes. The arrangement is consistent with any single antenna, multi channel commercial site. Base station TX2 formed the adjacent channel.

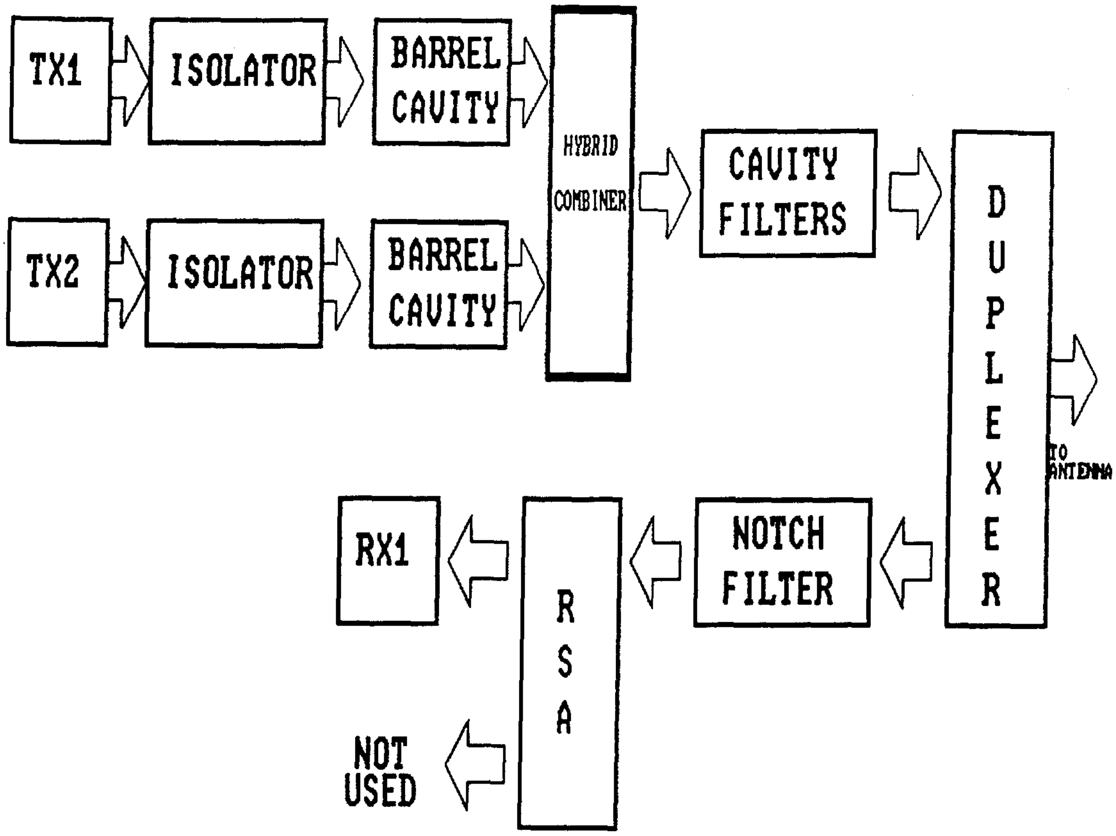


Fig 3.8 Base Station Configuration.

In order to simplify the experiments, modulation in the form of continuous speech was applied direct to TX2 to provide the required interfering adjacent channel signal.

Fig 3.9 Base Station.